Dynamics of Structures

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Dynamics of Structures

Progress Report 1993-1994

INTRODUCTION

Dynamics of Structures is a research programme sponsored by the Danish Technical Research Council. The programme started in 1993 and is planned to continue to the end of 1997. It is a cooperative effort of the Department of Building Technology and Structural Engineering and the Department of Civil Engineering at Aalborg University and the Department of Structural Engineering at the Technical Univerity of Denmark.

The purpose of the programme is to conduct research and to provide research education and results relating to dynamic loads and response of structures and foundations. Characterisation and modelling of materials under varying loads is also part of the research programme. The research will develop and use both analytical, numerical and experimental methods.

The problem areas dealt with in the research programme are: Analysis of Structures, Soil Mechanics and Wave Loads, System Identification and Damage Detection, Fatigue and Crack Propagation, and Man-Inuced Vibrations. This progress report is organized according to the structure of the original proposal with the following projects:

A: BASIC THEORY

- A1. Mode Shape and Reduced Base Techniques.
- A2. Wind Loads on Structures.
- A3. Dynamic Response of Structures with Stochastic Properties and Excitation.

B: EXPERIMENTAL TECHNIQUES

- B1. Damage Detection in Structures under Random Loading.
- B2. Modal Analysis Based on Random Decrement Signatures.
- B3. Fatigue and Crack Propagation.

C: SELECTED DYNAMIC PROBLEMS

- C1. Behaviour of Soil Subjected to Dynamic Loads.
- C2. Dynamic Response of Coarse Granular Materials to Wave Load.
- C3. Dynamics of Sports Stadiums.
- C4. Dynamic Measurements on the Frejlev Mast.

GENERAL STATUS

The project structure of the research programme conforms closely with that of the original proposal. The following changes have occurred: The contents of Project C1 has been adjusted following the untimely death of Professor Moust Jacobsen, Project A3 has been continued and now covers the activities of an AUC-financed Ph.D. student relating to the subject, and Project C4 is a specific activity originated within Projects B1 and B2 and planned to start in 1995.

Summary of Research

Within basic theory substantial progress has been made concerning a generalized eigenvalue algorithm for dynamics and stability problems, a solution technique for nonlinear finite element problems, and modelling and simulation of structures with stochastic properties. Also some work has been made on wind loads. Details are given in sections A1-A3 below.

The experimental techniques have concentrated on damage detection and crack propagation. The work on damage detection covers ARMA modelling and system identification and Random Decrement technique as described in B1 and B2. Damage detection by neural network techniques has also been considered. The crack propagation work of B3 has concentrated on failure of concrete, but will concentrate on fatigue crack propagation in 1995.

The geotechnical projects C1 and C2 have covered foundation design of breakwaters, experimental characterisation of granular materials and dynamic properties of soils, and theoretical material models for granular materials. Work on man-induced vibration from spectators has been initiated in 1994 in project C3, and a new project C4 is planned for dynamic measurements and system identification of a large guyed mast.

All projects in the original plan have been started. The status is satisfacory on all projects and many external relations have been established. In particular the four projects A1, A3, B1 and C2 have a very high level of activity, clearly demonstrated in the substantial number of publications.

Research Education

The research programme finances five Ph.D. students, and one additional Ph.D. student is financed by Aalborg University and attached to project A3. Aalborg University has contributed to financially to two of the Ph.D students in the research programme as illustrated in the Table, giving dates and relative financing in months.

Table 1: Ph.D. student enrollment in programme

Ph.D.	Project	Period	AUC	STVF
Steffen Vissing	A1	01.01.93-31.12.95	0	36
Poul S. Skjærbæk	A3	01.09.94-31.08.97	36	0
Palle Andersen	B1	01.09.93-14.02.97	6	30
John Asmussen	B2	01.09.94-31.08.97	6	30
Lars Bødker	C1	01.07.94-30.06.97	0	36
Th. Cornelius Hansen	C3	01.01.93-31.12.97	0	36

External Contacts and Information

Most projects have established international working contacts as indicated in sections on the individual projects. The research programme will receive a three months visit via the EU Human Mobility Programme, and also interacts with the EU Marine Science and Technology (MAST) Programme.

An information leaflet 'Dynamics of Structures' was sent out in June 1994 together with an invitation to a workshop on dynamics of structures 14-15 September, 1994. The workshop contained presentation of laboratory facilities at Aalborg University for Dynamics of Structures and 14 presentations - 10 from the research programme and 4 external. The manuscripts of the presentations were made available during the workshop. A total of 25-30 attended the workshop, that was generally considered a success. It is the intention to have a workshop every year of the programme, and an effort will be made to increase the number of external participants.

A: BASIC THEORY

A1. Mode Shape and Reduced Base Techniques

Project content and status

The purpose of the project is to develop computational techniques suitable for models with a large number of degrees of freedom in which a reduced basis is used for the full of a limited part of the problem. The main effort has been devoted to the reduction and efficient solution of the generalized eigenvalue problem. This problem plays a central role in structural dynamics and stability. Also a nonlinear solution technique based on orthogonal increments has been developed.

The vibrations of undamped or damped structures are described by the generalized eigenvalue problem of linear and quadratic type, respectively.

$$(\mathbf{A}+\lambda\mathbf{B})\mathbf{w} \;=\; 0 \qquad\qquad (\mathbf{K}+\lambda\mathbf{C}+\lambda^2\mathbf{M})\mathbf{u} \;=\; 0$$

In structural dynamics the quadratic eigenvalue problem for damped vibrations is often reduced by imposing restrictions on the damping matrix $\mathbf{C}$ to produce a simple modification of a linear eigenvalue problem. Essentially this amounts to an assumption of uncoupled real modes - i.e. modes with all components in phase. For nontrivial damping the mode shapes as well as the eigenvalues will typically be complex valued.

Preliminary work in 1993 included algorithms for the subspace method for the linear eigenvalue problem. A subspace containing the smallest eigenvalues is found by inverse iteration combined with orthogonalisation to speed up convergence. The algorithms are reported in [A1.1] and [A1.2] including a computer code implementation in C.

The work in 1994 has concentrated on the reduction of quadratic and linear eigenvalue problems to a smaller linear eigenvalue problem of tridiagonal form and the development of an efficient solution method for the reduced problem. The reduction is performed by the Lanczos scheme, in which each iteration increases the dimension of the subspace by one. Work was concentrated on problems with symmetric matrices, and it was realized, that the natural form of the reduced tridiagonal problem, did not use the standard unit matrix, but a diagonal matrix $\mathbf{E}$ containing a combination of +1 and -1 entries, i.e. a symmetric eigenvalue problem of the form

$$(\mathbf{E}+\lambda\mathbf{T})\mathbf{x} \;=\; 0$$

While this eigenvalue problem is symmetric and tridiagonal, the nondefinite form of the matrix $\mathbf{E}$ permits complex eigenvalues. A common procedure for the reduction of linear and quadratic eigenvalue problems to this - non-classic - form has been developed and described in [A1.8] and [A1.10].

The new reduced tridiagonal eigenvalue problem with nondefinite diagonal matrix $\mathbf{E}$ can not be solved by traditional algorithms without destroying its particularly simple and compact form. The traditional method of choice would be the **QR**-algorithm with appropriate shifts. However in the present case this would imply the use of an upper Hessenberg matrix and a unit matrix, instead of the *symmetric* tri-diagonal matrix $\mathbf{T}$ and $\mathbf{E}$. An alternative formulation of the **QR**-algorithm has been developed, that retains the symmetric tri-diagonal form. Like in the original **QR**-algorithm the use of appropriate shifts during iteration is crucial for the efficiency of the algorithm. The reason appears to be that the eigenvalues are liberated in order of increasing magnitude, and if the right shifts were not used, most of the iterations would be used to reshuffle the tridiagonal matrix, one step at a time. Complex aritmetic can be avoided by combining two conjugate complex single shifts into a real-valued double shift. The new generalized **QR**-algorithm with real-valued double shifts is described in [A1.11].

The work on non-linear solution techniques has resulted in the development of the 'orthogonal residual' type of algorithm. The idea is to consider the displacement increment as a 'modal form' that can be increased or decreased in magnitude by the out-of-balance force while retaining its shape. The current magnitude is optimal, if the residual is orthogoanl to the 'modal form'. The original algorithm was reported in [A1.3], and an extension with quasi-Newton correction in [A1.6]. Both papers are in the process of publication as journal articles. Presentation of these methods and their relation to alternative nonlinear solution methods have been given at several conferences [A1.4], [A1.5], [A1.7] and [A1.9].

Plans for 1995

The main task within this project will be the further analysis of the generalized Lanczos reduction and QR algorithm for non-definite linear and quadratic eigenvalue problems with respect to convergence, stability, and efficiency. In particular the quadratic generalized eigenvalue problem corresponding to dynamic systems with nonorthogonal damping will be investigated. In this problem the solution efficiency hinges on the ability of the generalized Lanczos procedure to extract the relevant information in a *limited* number of modes, and the convergence and stability of the generalized QR algorithm with double transformations, accounting for complex conjugate eigenvalues.

Dynamic analysis facilities will be included in the finite element program FEMLAB developed by Krenk & Hededal in 1994 and used to study large order problems on PC and workstation computers. A comparative study with traditional nonsymmetric solution procedures will be carried out, and the use of shifts and different forms of reorthogonalization in the generalized Lanczos reduction procedure will be investigated.

Steen Krenk will mainly be at the Division of Mechanics at Lund University, Sweden in 1995. The project will cooperate with the group working on vibrations and fluid structures interaction at the Division of Structural Mechanics in Lund. Also, contact has been established with a new project on nonsymmetric eigenvalue-problems and fluid-structure interaction at the Technical University of Delft, and Hilda van der Veen will visit during 1995. Steffen Vissing will spend several shorter periods in Lund and Delft during 1995.

Participants

Steffen Vissing, Ph.D. student, Departement of Building Technology and Structural Engineering, Aalborg University. Financed by the research programme from 1.1.1993.

Steen Krenk, Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

√ A1.1 S. Vissing & S. Krenk, A generalized Jacobi algorithm, Engineering Mechanics Paper No. 15, Aalborg University, June 1993.

√ A1.2 S. Vissing & O. Hededal, A subspace algorithm, Engineering Mechanics Paper No. 17, Aalborg University, June 1993.

√ A1.3 S. Krenk, An orthogonal residual procedure for nonlinear finite element equations, *International Journal for Numerical Methods in Engineering* (in press). Engineering Mechanics Paper No. 18, Aalborg University, July 1993.

A1.4 S. Krenk, Solution of nonlinear finite element equations by an orthogonal residual procedure, *Progress in the Theory and Application of the Finite Element Method II*, Chalmers University, Göteborg, August 26-28, 1993.

√ A1.5 S. Krenk, A unified approach to nonlinear finite element solution procedures, *Sixth Nordic Seminar on Computational Mechanics*, Linköping, October 18-19, pp. 3-18, 1993.

A1.6 S. Krenk & O. Hededal, A dual orthogonality procedure for nonlinear finite element equations, *Computer Methods in Applied Mechanics and Engineering* (in press). Engineering Mechanics Paper No. 21, Aalborg University, November 1993.

A1.7 S. Krenk & O. Hededal, Orthogonal residual solution procedures, *WCCM III, Third World Congress on Computational Mechanics*, Extended Abstracts Vol. II, pp. 1304-1305, Chiba, Japan, August 1-5, 1994.

A1.8 S. Vissing & S. Krenk, Linear and quadratic Lanczos algortihms, *Seventh Nordic Seminar on Computational Mechanics*, Ed. K. Bell, Trondheim, October 4-5, pp. 92-95, 1994.

A1.9 S. Krenk, Orthogonal residual procedures in non-linear mechanics, *DCAMM Anniversary Volume 1994*, Danish Center for Applied Mathematics and Mechanics, Lyngby, October 27-28, pp. 79-98, 1994.

A1.10 S. Vissing & S. Krenk, Linear and quadratic Lanczos algorithms, Engineering Mechanics Paper No. 25, Aalborg University, December 1994.

A1.11 S. Vissing & S. Krenk, Generalized QR algorithm for indefinite symmetric eigenvalue problems, Engineering Mechanics Paper No. 26, Aalborg University, December 1994.

A2. Wind Loads on Structures

Project content and status

The purpose of the project is to establish procedures and collect data for calculation of dynamic wind loads on structures. This includes in particular: wind field representation, extreme wind statistics, dynamic alongwind response, and vortex shedding response. The project is closely related to the dynamic wind response design problems treated in a preliminary form in the new Eurocode 1, Actions on Structures. Improved procedures for calculaing dynamic wind loads and response may have impact on the revision of the Eurocode, planned to take place within 3-4 years.

A wind field simulation procedure has been developed in cooperaion with Jacob Mann at Research Establishment Risø [A2.1]. The influence of the wind gradient on the turbulence is included via a perturbation solution to the Navier-Stokes equations, and good agreement with turbulence measurements is obtained.

The extreme winds in the eastern part of Denmark have been estimated from available data in connection with the Øresund Bridge project. In the present project directional characteristics of the extreme winds for all Denmark will be determined, using the so-called peak-over-threshold method. Three alternative formulations, based on either of the variables wind velocity, wind velocity squared, and wind pressure, are being investigated.

Dynamic along wind response is usually evaluated on the basis of an approximate representation of the structure in the wind field. An improved representation, in which the two dimensions of the structural shape are repreented in a simple explicit format, has been developed and presented to a task gorup for wind load, [A2.2].

Plans for 1995

The investigation of the dynamic extrem wind climate in Denmark will be completed, and the results will be published and included in the Danish design specifications of the Eurocode. A more detailed analysis of the along wind response procedure will be made, including the effect of the length scale of the turbulent wind field. The results will be published and distributed to the members of the Eurocode team on wind load in attempt to improve the present code procedures for dynamic wind load.

There is a general need for design procedures for structures suceptible to vortex shedding. The design procedure must include the essential features, such as shape and frequency, within a suitably simple format. A review of current procedures will be made and one and two degree of freedom systems will be analysed with regard to suitability. Wind tunnel tests will be made in the related project on Safety and Reliablilty of Structures, also sponsored by the Danish Technical Research Council. Part of this work will be carried by M.Sc. Michael Kleiser from Technische Univertität Wien, who will visit Aalborg University for three months in the beginning of 1995 as part of the activities of the Stochastic Mechanics Network under the EU Human Mobility programme.

Participants

Svend Ole Hansen, director and owner of S.O. Hansen ApS, a wind engineering and structural dynamics consulting company.

Steen Krenk, Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Søren R.K. Nielsen, Associate Professor, Depärtment of Building Technology and Structural Engineering, Aalborg University.

Michael Kleiser, M.Sc., Technische Universität Wien.

Publications and conferences

A2.1 J. Mann & S. Krenk, Fourier simulation of a non-isotropic wind field model, in *Structural Safety and Reliability, Proceedings of ICOSSAR '93*, Eds. G.I. Schuëller, M. Shinozuka & J.T.P. Yao, Balkema, Rotterdam, Vol. 3, pp. 1669-1674, 1994.

A2.2 S.O. Hansen & S. Krenk, Guidelines for Dynamic Alongwind Response, Technical Note for Task Group on Dynamic Wind Loading, Eurocode 1: Part 2.4 Wind Actions, pp. 9. September 1994.

A3. Dynamic Response of Structures with Stochastic Properties and Excitation

Project content and status

The purpose of the project is to formulate analytical models for the dynamic response of structures with random parameters subjected to stochastic dynamic excitation. The importance of uncertainty of structural parameters such as the reduced bending stiffness in cracked RC-beams are investigated. A finite element program for RC-structures is developed with due consideration of the deterioration of strength and stiffness of structural elements because of bond deterioration, cracking, crushing etc. The programme will be verified by comparing the predicted response with measured values from model tests. Also localization of damages in RC-structures based on measured eigenfrequencies is considered. The robustness and effectiveness of the localization algoritm are tested based on simulated results from the finite element program [A3.1].

The work on the formulation of analytical models for the dynamic response of structures with random parameters subjected to stochastic dynamic excitation has been done in cooperation with H. U. Köylüoğlu and A. Ş.Çakmak, Princeton University, USA. Solutions have been obtained based on first and second order perturbations methods - for linear systems in [A3.2], linearized nonlinear systems in [A3.1], and with a hierarchial approach in [A3.4]. Another solution has been based on stochastic differential equations, introducing the random parameters as extra state variables, [A3.5]. In this case secular terms arising in the transient phase of the response can be omitted. Finally, an non-stochastic interval mapping approach has been applied, and an approach for calculating the failure probability of random structures with many safety margins by mapping the crossing problem into a modal subspace, [A3.6].

The damage localization problem and the response problem has only been considered in a preliminary phase. A method for the prediction of global and localized damage and future reliability for RC-structures subject to earthquakes has been developed based on updating the parameters of an equivalent shear model of hysteretic oscillators, [A3.7]. Further, an approach based on modelling the response by means of neural networks has been attempted, [A3.8].

The project has developed satisfactory during 1994, and all goals have been achieved. Most of the research during 1994 has been financed by the Aalborg University (Søren R.K. Nielsen).

Plans for 1995

By March 1995 a Ph.D. student, Poul S. Skjærbæk, will be attached to the project. Poul S. Skjærbæk will be financed by Aalborg University in support of the effort on dynamics of structures. The project deals with the formulation of numerical models for the response of RC-structures subject to random loadings. Further the possibility is investigated of using global damage indicators estimated from response measurements to detect and localize damage in the structure. It is the plan, that Poul S. Skjærbæk shall concentrate on the development of the finite element program for RC-structure calculations and the damage location problem.

The initial task in the project is to develop a simulation programme for stochastic dynamic analysis of RC-structures which is able to handle panel buildings (structures of slabs and beams). This work will be based on modification of an existing programme SARCOF which has been designed for the analysis of framed structures. Specific slab elements will be developed, taking the stiffness and strength deterioration into account. The stochastic load modelling will still be concentrated on earthquakes.

Based on simulation studies with this programme, the work will next be concentrated on the development of a algoritm for localization of damage in RC-structures subjected to earthquakes. The localization algoritm is based on measured time dependent circular eigenfrequencies $\omega_j(t)$ and damping ratios $\zeta_j(t)$. For a given undamaged jth substructure (ranging from a single beam to half a structure) a linear elastic stiffness matrix $\mathbf{K}_j$ can be assembled. An equivalent linear elastic stiffness matrix for the damaged jth substructure can then be defined as $\mathbf{K}_j D_j(t)$, where $D_j(t)$ is a local scalar damage indicator for the damaged jth substructure ranging from 0 to 1. The damage indicators $D_j(t)$ for the substructures, and hence the localization of the damage, are determined so the equivalent linear system posess the observed undamped circular eigenfrequencies. A similar approach is used for the damping matrix of the substructure, where the local damage indexes for the damping matrices of the substructures are calibrated to display the measured damping ratios.

The uncertainty of the localization is investigated by comparing the predicted localizations by the developed algoritm with simulated damage by SARCOF as a function of the number and location of the sensors.

Søren Nielsen will visit Princeton in 1995.

Participants

Poul S. Skjærbæk., Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University. Financed by the Aalborg University.

Søren R.K. Nielsen, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

A3.1 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Stochastic dynamics of geometrical non-linear random structures subject to stationary random excitation, *Journal of Sound and Vibration* (in press). Structural Reliability Theory, Paper No. 116, Aalborg University.

A3.2 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Perturbation solutions for random linear structural systems subject to random excitation using stochastic differential equations. Structural Reliability Theory, Paper No. 117, Aalborg University (submitted to *Earthquake Engng. Struct. Dyn.*).

A3.3 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Applications of interval mapping in mechanics for structural uncertainties and pattern loadings. *Journal of Engineering Mechanics* (in press).

Structural Reliability Theory, Paper No. 121, Aalborg University.

A3.4 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Perturbation solutions for non-linear MDOF structures with random properties subject to random excitation using stochastic differential equations. Structural Reliability Theory, Paper No. 133, Aalborg University (submitted to *IUTAM'95*, Trondheim).

A3.5 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Solution of random structural system subject to non-stationary excitation: Transforming the equation with random coefficients to one with deterministic coefficients and random initial conditions. Structural Reliability Theory, Paper No. 134, Aalborg University (submitted to *Earthquake Engineering and Soil Dynamics*).

A3.6 S.R.K. Nielsen, H.U. Köylüoğlu & A.Ş. Çakmak, Reliability approximations for random MDOF structures subject to random dynamic excitation in modal subspaces. Structural Reliability Theory, Paper No. 126, Aalborg University (submitted to *ICASP'95*, Paris).

A3.7 S.R.K. Nielsen, H.U. Köylüoğlu, A.Ş. Çakmak and P. H. Kirkegaard, Prediction of global and localized damage and future reliability for RC-structures subject to earthquakes. Structural Reliability Theory, Paper No. 128, Aalborg University (submitted to *Earthquake Engineering and Structural Dynamics*).

A3.8 S.R.K. Nielsen, H.I. Hansen & P.H. Kirkegaard, Modelling of Deteriorating RC-Structures under Stochastic Dynamic Loading by Neural Networks. *Proc. of the 2nd Int. Conf. on Computational Stochastic Mechanics*, Athens, Greece, June 13-15, 1994. Structural Reliability Theory, Paper No. 125, Aalborg University.

B: EXPERIMENTAL TECHNIQUES

B1. Damage Detection in Structures under Random Loading

Project content and status

The main goal is to develop a robust damage detection technique based on the calibration of the ARMA models for detecting, locating and quantifying damages in structural systems. This includes an investigation of the uncertainties of the modal parameters and mode shapes obtained by time domain ARMA-models for identification of civil engineering structures, and the development of suitable software in a PC environment.

The project started in September 1993 with Ph.D-student Palle Andersen who made a first version of an ARMA calibration programme in C++ based on a Gauss-Newton optimization algorithm. Other optimization algorithms for calibration of ARMA models have been investigated, in particular with regard to estimation and setting of starting values in the ARMA algorithms, which may influence the modal parameters. Also the handling of large data segments and implementation of multi-channel ARMA models have been considered. The resulting preliminary version of a C++ programme for calibration of ARMA models was presented in the September 1994 workshop on "Dynamics of Structures", and a paper presenting a "backward-forecasting" algorithm for ARMAX-models and a comparison with the traditional Gauss-Newton algorithm has been submitted to IMAC13, [B1.1].

In parallel with the development of the C++ programme the ARMA calibration algorithms have also been implemented in MATLAB together with other techniques (ERA,ITD,..) for time domain identification of civil engineering structures. The MATLAB programme is in the form of a STDI-toolbox, (Structural Time Domain Identification) to be used with MATLAB. The development of this toolbox started using a DOS-version of MATLAB, but was later changed to the Windows version in order to use the graphics user interface.

The project also contains a part dealing with damage detection. The software has used in a project on damage detection of concrete beams. In cooperation with the 'Size Effects and Rotation Capacity of Concrete Beams' - sponsored by the Danish Technical Research Council - three concrete beams were made in the summer 1994. These beams were loaded using a traditional servo-hydraulic loading-system in displacement control. At each reloading the beams were excited by a series of pulses using an impact hammer. The measured response was analysed using the C++ ARMA calibration programme. It was found that it was easier to detect a damage in a normally reinforced beam than in a lightly reinforced beam, [B1.2].

Data from one years measurements of the dynamic response of an offshore structure have been obtained from the consulting company INTEVEP A.S in Venezuela and have been analysed with respect to linearity, stationarity, periodicity and normality. Further, the modal parameters have been estimated using an ARMA model [B1.3]. Based on this analysis the possibility of detecting a change in the structure, due to e.g. a damage, has been investigated [B1.4]. Data from the Norwegian Gullfaks offshore platform - obtained from Ivar Langen, Høgskolesenteret i Rogaland - have also been analysed.

Damage assessment consists of locating and quantifying a damage from estimated modal parameters. In order to solve this problem well-known techniques have been considered and a new neural network based has been proposed. This neural network based technique has been tried out on steel beams in the laboratory [B1.5], [B1.6] and on a 20 meter high steel lattice mast [B1.7]. The technique has been compared with well-known techniques [B1.8], [B1.9]. The results from these investigations show that the neural network based technique is superior to other techniques. Especially, due to better results and because it is a technique which can be used on-line.

In 1994 the problem of optimal location of sensors has also been considered. By using a scalar measure of the inverse of the Fisher Information Matrix it is shown in [B1.10] how optimal locations of sensors can be estimated.

In addition to the contact with INTEVEP A.S. cooperation has been established with Anders Rytter from the Applied Mechanics Unit of the European Laboratory for Structural Assessment in Ispra, Italy. In 1994 this cooperation was mainly done in relation to development of the neural network based technique for damage assessment. Further, there has been some research concerning damage assessment of a full-scale 4 storey RC-structure located in the laboratory in Ispra. In this research the neural network based damage assessment technique has been evaluated on a RC-structure. This work has been completed [B1.11]. A FEM model for a steel beam with a crack has been established together with Anders Rytter and Marek Krawczuk from the Polish Academy of Sciences, and the modal parameters calculated using the FEM have been compared with experimentally obtained modal parameters, [B1.12].

A working relation has been established with the subgroup 'monitoring and evaluation' of EG-SEA-AI (European Group for Structural Engineering Applications of Artificial Intelligence). Goals for this group, the name of the participants etc. can be found at the HTTP server *http://www.fen.bris.ac.uk/civil/egseaai-/mande.html.*

The project also cooperates with Dr. Demosthenous, Greece, and Rune Brincker visited Dr. Demosthenous in the summer 1994 in order to present the possibility of using ARMA models for analysis of earthquake data [B1.13].

Plans for 1995

The work on ARMA models include: model reduction and separating closely spaced modes, implementation of a multi-channel ARMA model, and estimation of the uncertainty of modal parameters. In addition there are plans for full-scale measurements on the laboratory steel lattice mast for $\frac{1}{2}$ - 1 year with the aim to establish a robust monitoring system which samples data each time a given trig-condition is exceeded. Various kind of damage will be introduced in the mast during the measurement period. This implies a large amount of data which have to be analysed, thereby complicating the damage assessment. A separate goals is to develop suitable software.

The STDI-toolbox will be completed, and a 'Unified Damage Indicator'. combining changes in several response properties and based on probability of detection will be developed.

Techniques which can be used to solve the inverse damage assessment problem will be considered. Fuzzy logic combined with neural networks seems a to be technique which may be considered.

Palle Andersen will be on maternatiy leave from 9 January to 26 March 1995, and it is intended that he spend 3-4 months in the autumn at a foreign university.

Visits by Prof. Ibrahim, Old Dominion University, and Prof. Piombo, Torino University, are being negotiated.

The cooperation with INTEVEP A.S. 1995 will be discussed at IMAC13 in February 1995. Furthermore a meeting in EG-SEA-AI following the IABSE Colloquium i Bergamo, March 1995, is planned.

Participants

Palle Andersen, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University. From 1.9.1993, financed by the research programme from 1.3.1994.

Rune Brincker, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

√ B1.1 P. Andersen, R. Brincker & P.H. Kirkegaard, On the uncertainty of identification of civil engineering structures using ARMA-models. (to be presented at *IMAC13*, Nashville, 16-19 February 1995).

√ B1.2 R. Brincker, P. Andersen, P.H. Kirkegaard & J.P. Ulfkjær, Damage detection in laboratory concrete beams. (to be presented at *IMAC13*, Nashville, 16-19 February 1995).

√ B1.3 P.H. Kirkegaard, J.C. Asmussen, P. Andersen & R. Brincker, An experimental study of an offshore structure. Fracture & Dynamics Paper, No. 59, Aalborg University, 1994.

√ B1.4 R. Brincker, P.H. Kirkegaard, P. Andersen & M. Matinez, Damage detection of an offshore structure. (to be presented at *IMAC13*, Nashville, 16-19 February 1995).

√ B1.5 P.H. Kirkegaard & A. Rytter, Vibration based damage assessment of a cantilever using neural networks. *10th International Conference on Experimental Mechanics*, Lisbon, 1994.

√ B1.6 P.H. Kirkegaard & A. Rytter, Use of neural networks for damage assessment of civil engineering structures. *1st AI-SEA-AI Workshop*, Lausanne, 1994.

√ B1.7 P.H. Kirkegaard & A. Rytter, Use of neural networks for damage assessment of a steel mast. *IMAC12*, Honolulu, 1994.

√ B1.8 A. Rytter & P.H. Kirkegaard, Vibrational based inspection of a steel mast. *IMAC12*, Honolulu, 1994.

√ B1.9 P.H. Kirkegaard & A. Rytter, A comparative study of different vibration based damage assessment techniques. (to be presented at the *IABSE Colloquium*, Bergamo, 1995.

B1.10 P.H. Kirkegaard & R. Brincker, On the optimal location of sensors for parametric identification of linear structures. *Journal of Mechanical Systems and Signal Processing*, Vol. 8, No. 4, 1994.

B1.11 A. Rytter, P. Negro & P.H. Kirkegaard, Vibrational based inspection of a four storey RC-building. (to be presented at the *International Workshop on Structural Damage Assessment using Advanced Signal Processing Procedures*, Pescara, May 29-31, 1995.

B1.12 A. Rytter, M. Krawczuk & P.H. Kirkegaard, An experimental and numerical study of the modal parameters of a damaged cantilever. (to be submitted for publication).

B1.13 P. Andersen & R. Brincker, On the perspectives of using ARMA models in earthquake engineering. Internal Note, Aalborg University.

B2. Modal Analysis Based on Random Decrement Signatures

Project content and status

One of the goals of the project will be to investigate the applicability of the 'Random Decrement Technique' (RDD) for estimation of frequency domain estimates such as a Frequency Response Function (FRF). Investigations of the applicability of parameter estimation based direct on RDD estimates will be an other goal. The goal of these investigations is a formulation of a technique which can be implemented for multi-output systems.

This project started 1.9.1994 with John C. Asmussen as Ph.D. student. A comprehensive information retrieval concerning RDD has been undertaken. Based on the information retrieval it was found, that most of the RDD literature deals with application problems. Only few researchers have considered the theory behind the RDD and implementation of the RDD, respectively. These problems will therefore be considered more closely. Various trig-conditions have been implemented.

In relation to the project the applicability of parameter estimation based direct on RDD estimates has been considered for the estimation of the coefficient of restitution of rocking systems [B2.1].

Plans for 1995

In 1995 work on the implementation of the RDD algorithm will be continued. In order to obtain a robust technique trig conditions, bias problems, and selection of the RDD-window will be considered. The main emphasis will be on lightly damped structures. It is intended that John Asmussen spends 3-4 months at a foreign university in the autumn.

This project will also benefit from the planned visits by Profs. Ibrahim Piombo mentioned in the B1 project.

Participants

John Christian Asmussen, Ph.D. student, Department of Building Technology and Structural Engineering, Aalborg University. From 1.9.1994, financed by the research programme from 1.3.1995.

Rune Brincker, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

B2.1 R. Brincker, M. Demosthenous & G.C. Manos, Estimation of the coefficient of restitution of rocking systems by the random decrement technique. *IMAC12*, Honolulu, 1994.

B3. Fatigue and Crack Propagation

Project content and status

The purpose of this project is to examine crack propagation behavior under dynamic load as well as static load mainly for the building materials steel and concrete, using a crack propagation theory. The project is separated into two parts: dynamic fatigue investigations of metals, and crack propagation in concrete. The main purpose is to verify a newly developed crack propagation formula based on a fracture energy balance.

A test series on metals with the purpose to investigate the dependence of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests have been analyzed using the crack propagation formula. It is shown that crack propagation under fatigue loading depends on the fatigue intensity K_{IC}, which will be further verified by comparing test results with theoretical calculations in 1995. The results have been presented in the report [B3.1].

An investigation of notched cubic test specimens of concrete was carried out in 1994, where snap back was successfully recorded. The results are being analyzed theoretically using the crack propagation formula and the results will be published in a report.

An investigation of concrete under triaxial compression was carried out in 1994. A report on the triaxial test results is under preparation [B3.2].

Some theoretical investigations on notched concrete beams using the crack propagation theory has been carried out. A report is under preparation [B3.3].

Plans for 1995

A test series on metals with the purpose to investigate the dependence of the critical stress intensity factor K_{IC} on the fatigue intensity K_I and a series of fatigue tests and hereby further verifying the results from [B3.1] are prepared and will be carried out in the beginning of 1995. Further development of a digital image system to measure crack propagation will also be undertaken. It is also the plan to investigate crack propagation in welded metal structures on the basis of the same theory, but this project is pending the results from the first part of the project.

At the Department of Structural Engineering, DTU, a test series to investigate the fracture mechanics behavior of concrete under compression is planned in spring 1995. The project is carried out in cooperation with several countries and organized by the RILEM 148 committee. This project is related to to the present research programme.

The studies of crack propgation under variable load will be given priority according to the original proposal.

Participants

Thomas Cornelius Hansen, Ph.D. student, Department of Structural Engineering, Technical University of Denmark. Financed by the research programme from 1.1.1993.

Mogens Peter Nielsen, Professor, Department of Structural Engineering, Technical University of Denmark.

Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

B3.1 T.C. Hansen, Fatigue and crack propagation, Report R316, Department of Structural Engineering, Technical University of Denmark, June 1994.

B3.2 T.C. Hansen, Triaxial tests on concrete, Department of Structural Engineering, Technical University of Denmark, (in preparation).

B3.3 T.C. Hansen & D.H. Olsen, Fracture of Concrete, Department of Structural Engineering, Technical University of Denmark, (in preparation).

C: SELECTED DYNAMIC PROBLEMS

C1. Behaviour of Soil Subjected to Dynamic Loads

Project contents and status

The main purpose of the project is to investigate wave propagation in soil. The problems, which will be studied, will be linked to vibration of machine foundations, heavy traffic, trains etc. These cases are all related to dynamic problems concerning very small strain levels and relative high frequencies. To determine the response of the soil during dynamic loading it is necessary to determine the soil parameters under dynamic conditions. The parameters are Young's modulus, E, the shear modulus, G, and the damping of the material, D. These parameters will be functions of several parameters such as strain level, stress level, void ratio and saturation.

The project started 1.7 1994 with Lars Bødker as Ph.D. student. The project will concentrate on determination of the parameters for different kinds of Danish soils. The goal is to obtain some normalised curves to describe the variation of the three parameters according to strain and stress levels for each of the tested materials. All the test material will be fully saturated and the material will both include cohesive and non-cohesive soils. Laboratory test will be performed to determine the variation of the parameters. The laboratory tests will concentrate on resonant column test .

At the beginning of the project apparatus to determine E at stress states in the interval of 0-100 kPa and different strain levels was present at Aalborg University. The apparatus consists of a exciter table and a vacuum system to vary the stress states. During the tests acceleration at the top and bottom of the specimen will be measured, and from this measurement it is possible to calculate the E-modulus and the damping. From the start of the project and till now the work has been concentrated on extending the present equipment also to measure the G-modulus with bending elements. This is done by creating special pressure heads in which the bending elements is build in. The advantage of this is that it is possible to determine both the E-modulus and the G-modulus in the same specimen. The first test series have been carried out, and the used material is Yoldia clay from Nørre Lyngby in Northern Jutland. The Yoldia clay is used because of co-operation with the LITASEIS-project in which field measurements (seismic measurement) are compared with laboratory measurements.

The limit of the developed apparatus is that it is not possible to vary the strain level for the measurement of G. At Geonor, Oslo, the strain level using bending elements has been determined to be less than 10^{-6}, which normally is considered as the limit below which the G-modulus is assumed to be constant. Therefore, the measured G-modulus using bending elements is named G_{max}. To investigate the variation of the G-modulus with strain level the Drnevich resonant column apparatus is powerful. In this apparatus it is possible to measure both E-modulus and G-modulus at different stress and strain levels. Torsion of the specimen is used to determine the G-modulus, and because of this hollow specimen is used. The hollow specimen is important to get a well-defined strain level. It is planned to buy a Drnevich apparatus in 1995.

Plans for 1995

In the beginning of 1995 Lars Bødker will visit NGI in Oslo for four months. The purpose of the visit is to get familiar with the Drnevich apparatus and to start a test series with the same material used in the already performed tests at Aalborg University. A part of the work at NGI will be to develop a new calibration procedure for the Drnevich apparatus. This is chosen to get a good understanding of the principles in the apparatus and because at NGI they are not convinced of the existing procedure.

The tests at NGI will both be resonant column tests to measure E and G at different strain levels and tests with bending elements to measure G_{max}.

After the visit test series at Aalborg University will be continued with the new Drnevich apparatus with different kinds of soil to describe the variation of E and G.

Participants

Lars Bødker, Ph.D. student, Department of Civil Engineering, Aalborg University. Financed by the research program since 1.7.1994.

Lars Bo Ibsen, Assistant Professor, Department of Civil Engineering, Aalborg University.

C2. Dynamic Response of Coarse Granular Materials to Wave Load

Project content and status

The project is related to the Marine Science and Technology II Programme (EU). The overall objective of the MAST II - program is to develop a rational method for the design of monolithic caisson structures on rubble foundation. The aim is to formulate a general document 'Design Guidelines for Vertical Caisson Breakwaters'. The special contribution from this present project is mainly to provide the soil mechanics part of the design tools. The project contains both theoretical and experimental work. The aim of the experimental work is to determine the characteristic strength and strain properties of non-cohesive soils under static and dynamic loadings. The properties will be investigated in both static and dynamic triaxial apparatus and by dynamic load plate tests. The CD and CU triaxial test will be installed into a new data base which fully developed, as a minimum will contain test with 3 relative densities for each of the selected materials. The material selected for testing must cover the grain fraction from fine sand to coarse gravel. The selected materials are indicated in Table 2.

Table 2: Results of the classification tests for the selected material

	Baskarp No. 15	Blokhus sand	Lund No. 0	Portland 8-16 mm	Portland 16-32 mm
d_{50} mm	0.14	0.17	0.35	12	20.5
$U = d_{60}/d_{10}$	1.78	1.5	2.2	1.56	1.42
d_s	2.644	2.646	2.647	2.642	
e_{max}	0.858	0.834	0.889	0.805	
e_{min}	0.549	0.565	0.524	0.611	

The theoretical work in 1994 has been concentrated on identification of failure modes and formulation of the corresponding bearing capacity formulas for monotonic loading of caisson breakwaters. The outcome of the study is going to be placed in the general document 'Design Guidelines for Vertical Caisson Breakwaters', [C2.1] and [C2.2]. These results have also been used to formulate reliability analyses of monolithic vertical wall breakwaters, [C2.3].

A new constitutive model for friction materials including the concepts of a characteristic line $q/p = M_c$ and an ultimate line $q/p = M_u$ within a general triaxial formulation has been developed [C2.5], [C2.6]. The model only requires 6 parameters: 3 for elastic and elasto-plastic stiffness (κ, λ, G), the slopes M_c and M_u of the characteristic and the ultimate state lines, and the initial ratio between shear and volume strain in a triaxial test. The model is in the format of elasto-plasticity with a generalized form of work hardening, in which the contributions from shear and dilatation are weighted. The model gives a good representation of test data in the loading regime for which is has been investigated [C2.6].

The experimental work carried out in 1994 has been static and dynamic triaxial tests on Baskarp no 15. The tests, CD, $CU_{u=0}$ and dynamic CU tests are run with a constant deformation speed varying from 4 to 100.000 % ph. By studying the basic phenomena in triaxial tests under uniform conditions identical responses of the soil due to static and dynamic loadings have been discovered. The static and dynamic responses of sand can be explained by the characteristic state and the strength of sand under undrained conditions is found to be controlled by the drained failure condition both for static and dynamic loadings, see [C2.4]. The static and dynamic tests has been reported in [C2.4]. For Blokhus sand and Lund No. 0 these test series have been carried out previously, and presently the tests are being installed into the data base. In order to perform static triaxial tests on the coarse gravel (Portland 8-16 mm and Portland 16-32 mm) a new 'large' triaxial apparatus has been developed and constructed. This new triaxial apparatus is identical to the apparatus on which the tests on sand (Baskarp, Blokhus and Lund) have been performed . The large triaxial cell allowed triaxial testing of 250 mm high cylindrical specimens with a diameter of 250 mm. This dimension of the specimen is a necessary consequence of the grain size. The production and installation of the new triaxial apparatus has been executed and CD tests on Portland 8-16 mm is started.

Plans for 1995

All the failure modes described in [C2.1] are kinematically admissible but not necessarily admissible which means that the presented bearing capacities may be on the unsafe side. To study the uncertainties introduced by the bearing capacity formulas the failure modes described in [C2.1] will be analysed by the finite element program ABAQUS.

Work on the constitutive model for friction materials will be continued. In particular development of numerical algorithms for implementation into a finite element program will be considered. Contact has been established with Prof. Rene de Borst and Arend E. Groen at the Technical University in Delft, and a visit by A.E. Groen in 1995 has been planned.

The CD tests on Portland gravel will be continued. 3 test series with different relative density is planed on Portland 8 - 16 mm and Portland 16-32 mm. . Dynamic triaxial tests on Lund and Baskarp sand , and static triaxial CD and CU tests on doublet height specimen will be performed. The tests program will be planed in such a way that the tests can support the the characteristic state models presented in [C2.4]-[C2.6].

Participants

Hans F. Burcharth, Professor, Department of Civil Engineering, Aalborg University.

Lars Bo Ibsen, Assistant Professor, Department of Civil Engineering, Aalborg University.

Steen Krenk, Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Marianne Borup and Jette Hedegaard, M.Sc. thesis students, Aalborg University.

Publications and conferences

√ C2.1 H.F.Burcharth & L.B.Ibsen : Response of Rubble Foundation to Dynamic Loading, *Proceedings of International workshop on Wave Barriers in Deepwaters*, Port and Harbour Research Institute Yokosuka, Japan Jan 10 - 14 , pp 402 - 417, 1994

√ C2.2 L.B.Ibsen: 5 Design Level 1 , Feasibility. Part of Design Guidelines for Vertical Caisson Breakwaters. version 1.1 November 4, 1994.

√ C2.3 C.S.Sørensen, L.B.Ibsen, A. Hansen & K.P.Jakobsen: Bearing Capacity of Caisson Breakwaters on Rubble mounds. Version 2 November 14, 1994

√ C2.4 L.B. Ibsen, Static and dynamic strength of sand, (submitted to the *Eleventh European Conference on Soil Mechanics and Foundation Engineering*, Copenhagen, 29 May - 1 June, 1995).

C2.5 S. Krenk, M. Borup & J. Hedegaard, A characteristic state model for sand. Engineering Mechanics Paper No. 24, Aalborg University, December 1994, (submitted to the *Eleventh European Conference on Soil Mechanics and Foundation Engineering*, Copenhagen, 29 May - 1 June, 1995).

C2.6 M. Borup & J. Hedegaard, *Characteristic State Modelling of Friction Materials*, M.Sc. Thesis, Aalborg University, January 1995.

C3. Dynamics of Sports Stadiums

Project content and status

In the current design of sports stadiums dynamic effects constitute an important part. The dynamic loads are mainly from wind and spectator movement. In both cases a good representation of the dynamic properties of the stadium as well as the load are necessary. Spectator motion can cause various types of periodic or transient dynamic loads. The periodic loads are mainly due to jumping, dancing, walking, body rocking and the special "wave" motion, seen at football matches. Transient loads primarily result from single impulse loads, such as jumping or falling from elevated positions. The response to these loads are of primary interest.

The purpose of this project is to develop a spectator load model that gives a realistic representation of the dynamic impulse or force and its spatial distribution. In this connection the validity of typical dynamic design assumptions for sports stadiums regarding eigenfrequencies, mechanical damping, mode shapes and amplitudes, will be investigated.

The main idea is to base the spectator load model on the impulses exerted by spectators on the structure. This may be done if the time period t_p of the individual impulse is small compared to the vibration eigenperiod T_n of the structure. One reason for specifying a load impulse is that the load function is very dependent on the type of motion and the interacting bodies, whereas the impulse corresponds to the time integral of the load function, which is independent of the shape of the function.

A preliminary parametric study of the accuracy of impulse analysis in structural dynamics has been performed for single degree of freedom systems. It has been found that impulse analysis can be used by introduction of a simple correction factor for time ratios t_p/T_n up to about 1. The possibility of using (subdivided) impulse analysis for larger time ratios still remains to be investigated. For t_p/T_n ratios greater than about 4 a quasi static response will probably be sufficient.

A small 80cm$\times$80cm measuring platform has been cast in concrete and installed with 4 force transducers. The platform is used to measure the vertical load from one person performing different in situ movements, such as jumping. The person is also equipped with an accelerometer at the waist to monitor the movements.

In connection with the project a visit has been made to Dr. Sven Ohlson, Unit for Dynamics in Design, Chalmers University of Technology, who has been working with man-induced dynamic loading.

Plans for 1995

The theoretical part of the project will include the following. The possibility of using simplified impulse analysis even for large t_p/T_n ratios will be investigated. Finite element analysis will be used to compare the structural response due to the exact load function with the structural response due to the equivalent (half-sine) impulse load. Finite element analysis will be used to make comparisons with the experimentaly determined dynamic mode shapes, eigenfrequencies and mechanical damping coefficients. It is the aim to formulate a simple impulse based recommendation for loads on grandstands and simmilar structures, as an alternative to the current use of static loads.

The experimental part of this project will be carried out in two main phases, one in the laboratory and another at a grandstand at a rock concert or a football match. In the laboratory there will be three stages. In the first stage the body motion and the load as a function of time will be measured on the small load platform mounted on a stiff laboratory floor for jumping and a 'wave' motion. This will be performed in december 1994 and january 1995. In the second stage the load platform will be mounted on a simple beam/plate structure and the measurements repeated on the beam both on and off the platform. In the third stage the effect of multiple persons on the beam will be measured. The beam will be analysed using experimental modal analysis, determining eigenfrequencies, mode shapes and damping coefficients. The second and third part will be performed during the first half of 1995. At the grandstand measurements will be performed for one person jumping, for multiple persons jumping and for a real situation either a concert or a football match. This second phase will be performed at a convenient time during 1995.

Jeppe Jönsson's employment at the Department of Building Technology and Structural Engineering ends in 1995. The project plans to employ Jeppe Jönsson the last 3 months of 1995 and 3 months in 1996. He will analyse experimental results, perform finite element analyses and develop a load model for design of spectator loads.

Participants

Lars Pilegaard Hansen, Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Jeppe Jönsson, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Publications and conferences

√C3.1 J. Jönsson & L. Pilegaard Hansen, Man-Induced Vibrations, *Dynamics of Structures, A workshop on dynamic loads and response of structures and soil dynamics*, Aalborg University, Denmark, September 14-15, 1994.

C4 Dynamic Measurements on the Frejlev-Mast

Project content and status

The purpose of the project is to evaluate the system identification programmes from the B.1 project on a real structure. This task will be carried out in this project in 1995 and the spring of 1996. The aim of this project is to make full-scale measurements on the Frejlev-mast which is a 200 meter high guyed steel mast located 10 km from Aalborg. Both the C++ programme and the programmes in the STDI toolbox will be evaluated. One of the goals will be to investigate the uncertainties of the modal parameters and mode shapes obtained by a practical application of time series models such as multi channel ARMA-models. Especially, problems concerning model reduction and separation of closely-spaced modes will be investigated.

The investigations of the Frejlev-mast will in part be done in cooperation with the consultant company Rambøll, Hannemann & Højlund, who are particularly interested in the forces in the cables. Therefore, an additional purpose of the project is to measure the strains in the cables.

Plans for 1995

In January-February 1995 the mast will be instrumented in order to measure strains in the cables. However, before the mast can be instrumented tests with the instrumentation and data acquisition equipment have to be performed in the laboratory. Also in January-February 1995 plans for the vibration measurements will be made. It is assumed that accelerometers, cup-anemometer and wind-vane can be mounted on the mast in Marts-April 1995. This means that preliminary tests with the strain-gauges and the vibration measurement equipment can be done during the first half of 1995. After the preliminary tests it is assumed that the instrumentation and data acquisition system have to be improved and corrected. This implies that monitoring of the Frejlev-mast will take place doing the autumn 1995.

Analysis of measurement data will be done from the start of the project. A final report will be finish in the spring of 1996.

Participants

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Lars Pilegaard Hansen, Senior Associate Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Poul Henning Kirkegaard, Assistant Professor, Department of Building Technology and Structural Engineering, Aalborg University.

Aalborg, 27 February, 1995.

Steen Krenk

Evaluation of research programme 'Dynamics of Structures'

Svend O. Hansen and Knut Andersen, programme committee, 10 February, 1995.

The purpose of the programme is to conduct research, provide research education and to obtain results relating to dynamic loads and response of structures and foundations. Modelling of materials under varying loads is also part of the research programme. Both analytical and experimental methods are developed and used in the research.

The research programme started in 1993 and it continues to the end of 1997.

The research programme is divided into three main topics consisting of basic theory, experimental techniques and selected dynamic problems. The research programme consists of 10 research projects totally.

Damage detection in structures has been a main issue in two of the research projects. The techniques developed will also be used in the planned full-scale experiments with the 200m high Frejlev-Mast (project C4), a project carried in corporation with the consulting engineering company Rambøll Hannemann & Højlund. Dynamic loads, such as wind load, wave loads and loads induced by spectator motions are also analysed in the research projects.

Foundation behaviour is an important design aspect of dynamically loaded structures, and two of the projects concentrate on soil behaviour and soil parameters under dynamic loading. One utilisation of the results of these projects is input to the formulation of a document on : "Design Guidelines for Vertical Caisson Breakwaters" in an EU Research Programme under MAST II.

There is a suitable interrelation between the methods used and results obtained in the different projects carried out.

The workshop arranged in September 1994 was a good mixture of presentations describing the results obtained in the research programme and presentations by consulting engineers showing the present methods used in practical design.

Main conclusion

The main conclusion is that the research programme meets all of its objectives. The research standard is very high and the results obtained in the projects have been published internationally in a large number of papers, some of those presented at international conferences. Good external relations to other Danish and foreign institutes and consulting engineering companies, as well as to other research programmes, have been established and continued.

The results obtained in the research programme will be useful for the industry and consulting engineers designing dynamically sensitive structures on land, offshore and along the coast. The trend towards lighter and more flexible structures makes the results obtained highly relevant for present and for future structural designs. The programme will provide knowledge and data to design dynamically sensitive structures more reliably and more economically.